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Organic amendment and minimum tillage in winter wheat grown in Mediterranean conditions: Effects on yield performance, soil fertility and environmental impact

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A B S T R A C T

The experiment was conducted to evaluate the agronomic benefit of the application of organic fertilizers combined with different soil tillage on quantitative and qualitative components of winter wheat (*Triticum durum* Desf., cv. 'Simeto') and on chemical soil fertility parameters. The environmental impact, due to heavy metals introduced in soil-plant system, was further investigated. Soil tillage treatments consisted of conventional (CT) and minimum tillage (MT). Fertilization treatments were: mineral at 100 kg N ha^{-1} (N_{min}); municipal solid waste compost at 100 kg N ha^{-1} (N_{comp}); 50 kg N ha^{-1} of both compost and mineral fertilizers (N_{mix}); sewage sludge at 100 kg N ha^{-1} (N_{ss}). These treatments were compared with an unfertilized control (N_0). No significant difference was observed between the two soil tillage treatments for quantitative yield production, while among the fertilization treatments N_{ss} did not show any significant difference compared to N_{min}. At the end of the research, the fertility of the soil (oxidable carbon, total nitrogen, available phosphorus) was on average higher in N_{comp} and N_{ss} treatments compared to the N_0 and N_{min} ones. The overall distribution of heavy metals in soil-plant system respect to the different fertilizer treatments has not allowed to grouped their effects with Principal Components Analysis. This result showed that the amount of potential pollutants applied by organic amendments did not modified the dynamic equilibrium of the soil–plant system. The MT, as well as the fertilization with the application of sewage sludge (N_{ss}), allowed to reach productive performance similar to conventional management (CT with N_{min}). Here we demonstrate that, in the short term period, sustainable agronomical techniques can replace the conventional one with environmental benefit.

1. Introduction

The large amount of degradable wastes produced by urban areas can have a negative impact on the environment if not adequately managed. In agriculture, the use of compost from organic municipal solid waste (OMSW) and sewage sludge (SS) offers the potential to recycle plant nutrients, thus reducing the use of mineral fertilizers. Organic urban wastes can be adequately processed in order to obtain an organic fertilizer after aerobic or anaerobic treatments. Aerobic transformation of organic wastes produces a stabilized and well humified material (compost), which is usually characterized by a slow mineralization rate in soil. Anaerobic digestate is made from organic substances, in a chemical reduced form, at low molecular weight, after degradation of complex organic substances as proteins, lipids, carbohydrates into less complex compounds (Montemurro et al., 2010). According to the starting material, OMSW and SS can be utilized as fertilizers because they consist of many essential plant nutrients like nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and other trace elements (Jamil et al., 2006). Both the application of OMSW compost and SS for agricultural purposes leads to positive changes in the chemical, physico-chemical and biologi-

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cal properties of soil, and this consequently increases plant yield (Veeresh et al., 2003; Jamil et al., 2006; Weber et al., 2014). Conversely, the OMSW compost and SS applications may lead to the accumulation of a number of potentially harmful components, and in particular heavy metals both in soil and crops. For this reason, in Italy the utilization of compost derived by OMSW or SS is subjected to law limitations by Italian Legislative Decree 75/2010 and 99/1992, respectively. Similarity in the European countries the use of sewage sludge is regulated by Directive 86/278/EEC. The presence of heavy metals in OMSW compost and SS can cause adverse effects to the environment, phytotoxic effects (Burns and Boswell, 1976), soil and water contamination and accumulation of heavy metals in food supplies (Keller et al., 2002; Bozkurt and Yarilgaç, 2003; Roca-Fernandez, 2013). However, chemical and physico-chemical characteristics of both soil and organic matrices can affect the interaction between heavy metals and soil-plant system. The bio-availability of heavy metals is linked to pH, organic content, texture, redox potential and soil cationic exchange capacity of soils (Street et al., 1977, 1978; Zwarich and Mills, 1979; Soon, 1981). Fuentes et al. (2004) indicated that the stabilization method of organic matter influenced the distribution of heavy metals and the phases to which they are bound. In particular, they found that the unstabilized sludge contained the highest accumulation of heavy metals in the most easily uptake fractions. Furthermore, the distribution pattern of macronutrients, micronutrients and other trace elements in topsoils is usually modified by tillage systems (Lavado et al., 1999). Blevins et al. (1983) and Lopez-Fando and Pardo (2009) indicated that the tillage techniques also affected some soil properties, as organic matter concentration or pH, determining changes in bioavailability of different elements. Several experiments have been conducted on the application of different OMSW composts (Eriksen et al., 1999; Bhattacharyya et al., 2003; Montemurro and Maiorana, 2007), and SS (Jarausch-Wehrheim et al., 1996; Boudjabi et al., 2008; Motta and Maggiore, 2013) as organic fertilizers, but there is still a lack of information on their positive and negative effects, and how the application of these products can interact with soil tillage, in order to achieve an agronomical and environmental sustainability in Mediterranean conditions.

This work aims to investigate the effect of using OMSW compost and SS as nitrogen source combined with different soil tillage systems for evaluating the agronomic response in winter wheat (*Triticum durum* Desf., cv. 'Simeto'). In addition, the effects of some potential hazards (heavy metals) introduced with organic amendments in the soil–plant system was also investigated.

2. Materials and methods

2.1. Experimental site

The experimental trial was carried out at Montescaglioso (MT), in southern Italy (40°38′55″N 16°37′1″E, 400 m a.s.l.), on a silty–clay soil. Before the experiment, the main physico-chemical characteristics of soil (Table 1) were determined, according to the Italian's Official Methods of soil analysis (Violante, 2000). This soil is slightly chalky surface and strongly calcareous deep alkaline reaction, has low permeability and is classified as Mollisol, Vertic Calcixerolls fine, mixed, active, thermic (Keys to Soil Taxonomy, 2014). In the layer of 0–40 cm depth, soil presents both low N (1.11 g kg^{-1}) and organic matter (19.5 g kg^{-1}) contents, slightly alkaline reaction (pH 7.2) and medium cation exchangeable capacity (17.8 cmol × kg^{-1}), as classified by Violante (2000).

The climate is accentuated thermomediterraean, as classified by UNESCO-FAO (1963), with winter temperatures that can fall below 0 °C, summer temperatures that can rise above 40 °C, and rainfall unevenly distributed during the year, being concentrated mainly in winter months. The mean annual rainfall during the three years field trial was 612 mm. Fig. 1 reports the mean monthly of temperatures and rainfall in the Montescaglioso (MT) station during the period of the experimental trial.

Table 1
Physico-chemical characteristics of the soil at the beginning (T_0) of the experiment.

Parameter	Unit of measure	Value
Sand	g kg^{-1}	200
Silt	g kg^{-1}	390
Clay	g kg^{-1}	410
Moisture	%	6.4
pH KCl		7.20
EC (1:5)	dS m^{-1}	0.22
CEC	cmol × kg^{-1}	17.8
Exchangeable Na	mg kg^{-1}	49.4
Exchangeable K	mg kg^{-1}	160
Exchangeable Ca	mg kg^{-1}	6126
Exchangeable Mg	mg kg^{-1}	639
Total N	g kg^{-1}	1.11
Available P	mg kg^{-1}	3.84
Oxidable Carbon	g kg^{-1}	11.3
C/N ratio		10.3
$Cd_{tot.}$	mg kg^{-1}	<0.5
$Cr_{tot.}$	mg kg^{-1}	40.9
$Cu_{tot.}$	mg kg^{-1}	13.4
$Ni_{tot.}$	mg kg^{-1}	29.5
$Pb_{tot.}$	mg kg^{-1}	8.52
$Zn_{tot.}$	mg kg^{-1}	54.2

2.2. Field trials

The study was carried out over a three-year period (from October 2010 to June 2013). In the three years of experiment, durum wheat was sown in the second half of November and harvested in second half of June. The experimental design was a split-plot with three replications. The wheat was grown in rotation with *Brassica spp.*, which is one of the typical rotation in the specific area, and the two crops were cultivated in the same year. Each elementary plot consisted of 9 m^2 (3 m length per 3 m wide). The main plot was characterized by two different tillage systems: conventional tillage (CT) and minimum tillage (MT). The CT treatment included moldboard plowing (40–45 cm deep) and both disk harrowing and vibrating tine cultivator two-three times, according with the environmental annual conditions, to prepare a proper seedbed. According with the usual practices in the specific area and soil conditions, we have introduced the MT treatment, which consisted of two disk harrowing at least 7 days between then and just one vibrating (10–15 cm deep). Within each tillage treatment, the following fertilizer strategies were compared: (i) mineral N (N_{min}) as urea, with 100 kg N ha^{-1}; (ii) OMSW compost application (N_{comp}), with 100 kg N ha^{-1} of total N (3.82 Mg ha^{-1}); (iii) compost and mineral application (N_{mix}), with 50 kg N ha^{-1} of organic N (OMSW compost) and 50 kg N ha^{-1} of mineral N; (iv) Sewage Sludge application (N_{ss}), with 100 kg N ha^{-1} of total N (1.81 Mg ha^{-1}). These different fertilization strategies were compared with an unfertilized control (N_0). The wheat crop management followed the normal procedures of the specific area, i.e., sowing density of about 400 seeds m^2, 13 cm of row spacing and weeds control Zadoks cereal development scale equal to 30 with specific chemical products. No disease controls were made during wheat cropping cycles and no chemical P and K fertilizers were added to cultivation, according with the consolidated practice of experimental area. For N_{min} treatment, mineral N was distributed before sowing and at seedling stage (Zadoks cereal development scale equal to 30) in two equal amounts. For N_{mix} treatment, the mineral N was applied only at seedling stage (Zadoks cereal development scale equal to 30), as well as in the N_{min} treatment. The OMSW com-